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(54) Abstract Title

Debris-free well casing explosive perforating system with shaped charge

(57) The present invention provides a well casing perforating system that produces less debris. In one embodiment, the debris-free perforating system includes a caseless shaped charge 12, fig.4, which may be densified eg with powdered tungsten, iron, copper or lead and may carried by a solid loading tube (36, fig.5), eg made from low-density or foamed plastics or paper. The loading tube can additionally be combustible and can be coated with an oxidizer to ensure incineration. The charge may comprise a binder of thermoplastics or thermosetting plastics, eg an epoxy resin, or a combination of both, eg a fluoropolymer. A thermoplastic-thermosetting binder may be made by blending thermoplastics and thermosetting components, curing the blend with a latent curing agent and coating the explosive particles with the cured blend. A fluoropolymer binder may be made by formulating a plastic bonded explosive using a water slurry process, pressing the powder to shape and exposing the moulded shape to electron radiation. The shaped charge may have a thin casing 10 and/or jacket 24, fig.6, eg of thin metal, glass or ceramic material.

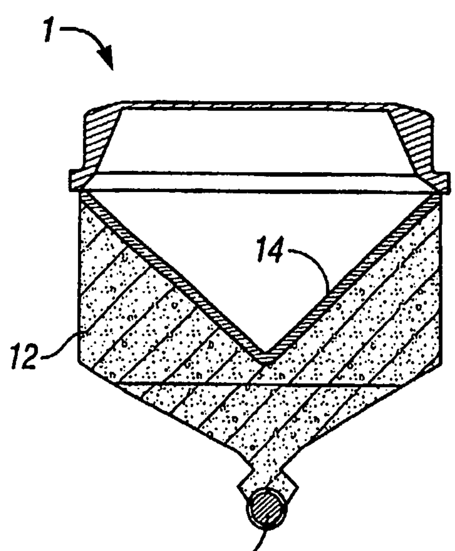

FIG. 4

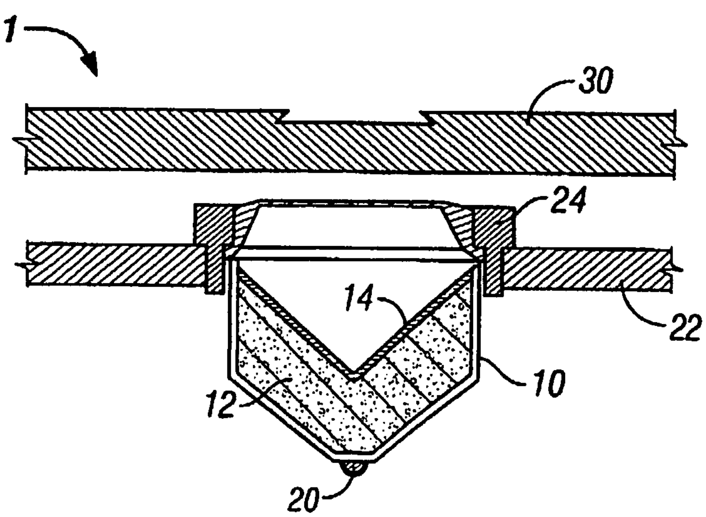

FIG. 6

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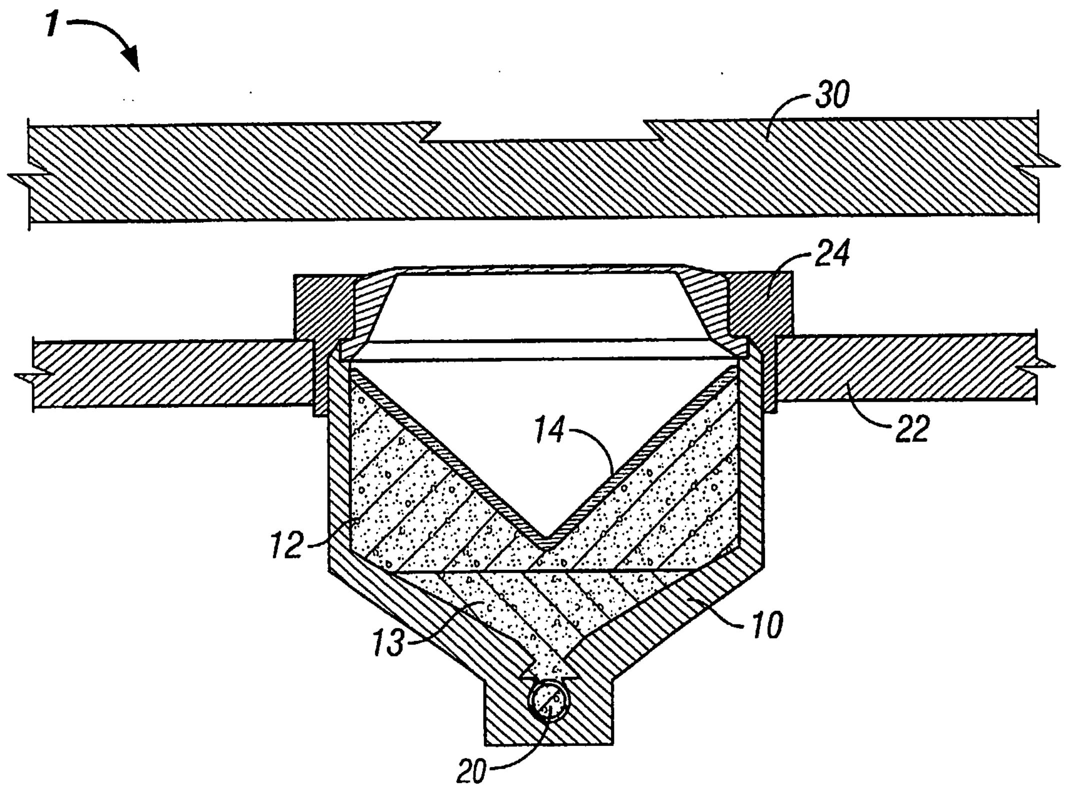

FIG. 1
(Prior Art)

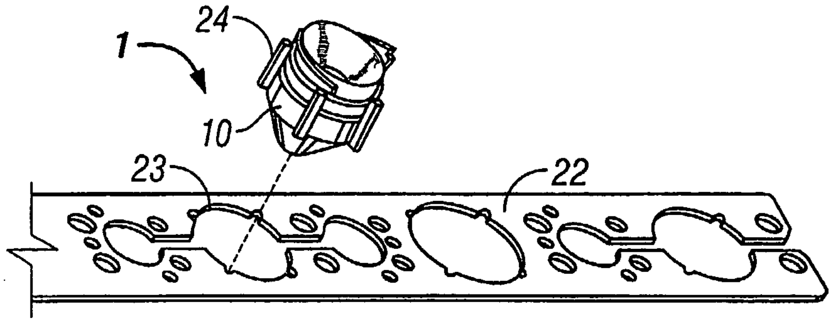

FIG. 2
(Prior Art)

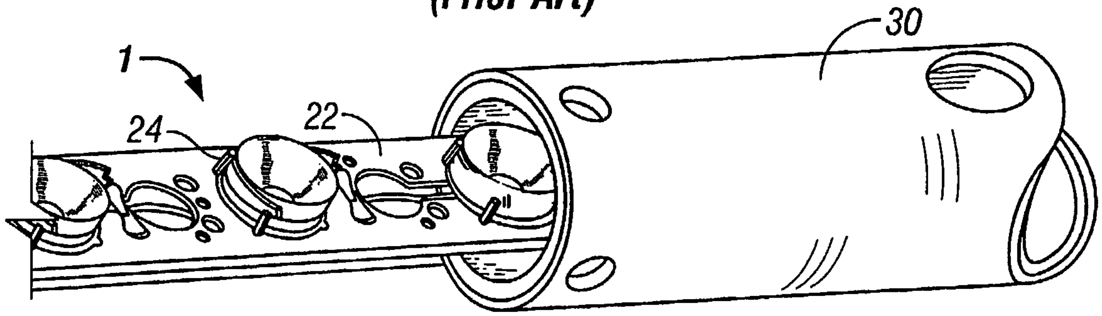

FIG. 3
(Prior Art)

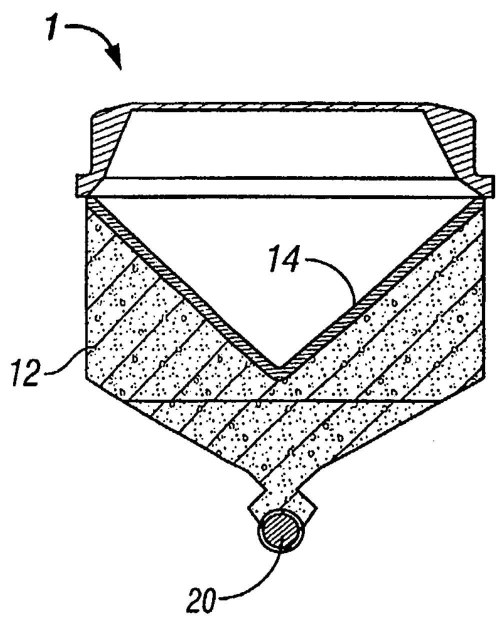

FIG. 4

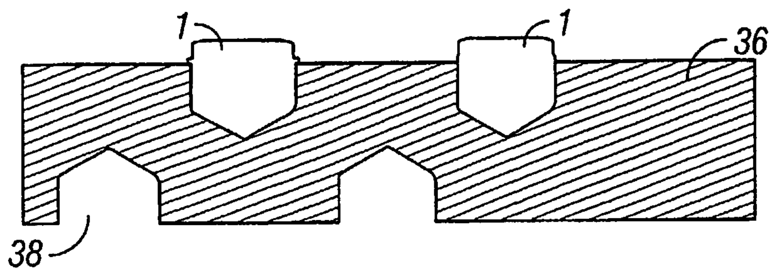

FIG. 5

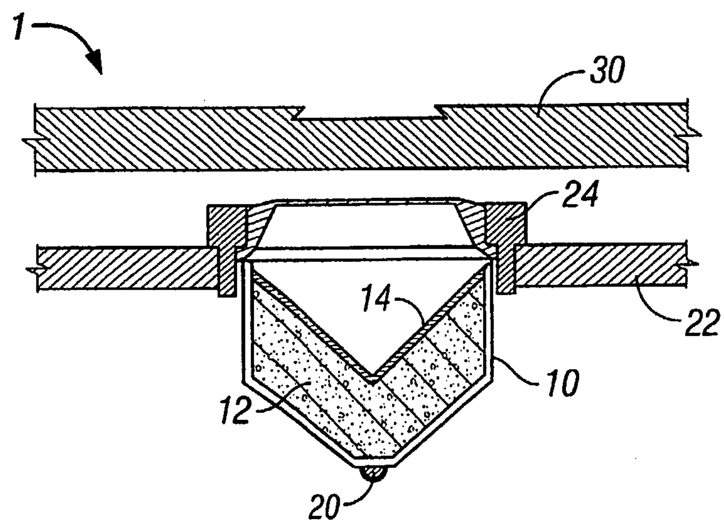

FIG. 6

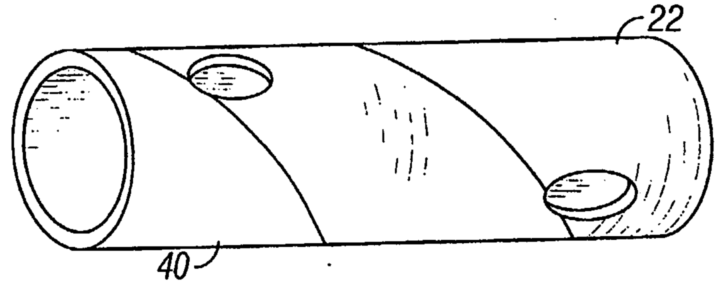

FIG. 7A

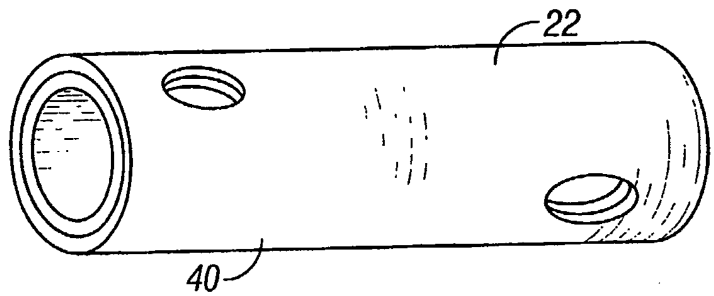

FIG. 7B

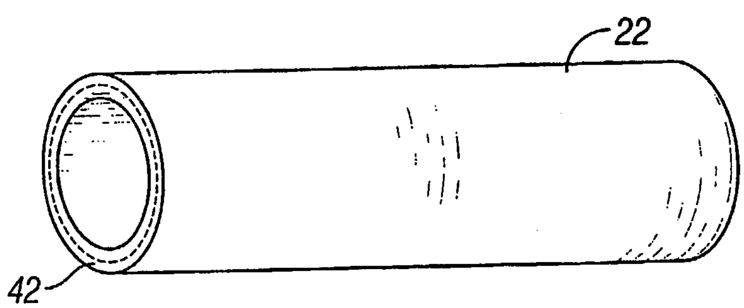

FIG. 7C

DEBRIS FREE PERFORATING SYSTEM

FIELD OF THE INVENTION

The subject matter of the present invention relates to a debris free perforating system. More specifically, the subject matter of the present invention relates to reducing the amount of debris generated during perforating with shaped charges.

BACKGROUND OF THE INVENTION

In drilling operations, the drilled hole is often lined with a casing to prevent the earth from filling the hole. In order for the surrounding fluid to enter the drilled hole, the well casing must be perforated. Such operation is typically performed by a perforating gun loaded with one or more shaped charges.

Conventional perforating guns produce significant debris upon detonation of the shaped charges. The generated debris can enter the well fluid and become entrained in the well fluid. As the debris is carried by the well fluid, it can complicate down stream processing of the well fluids by clogging filters and jamming pumps, for example.

Extensive research on hollow carrier perforating guns indicates that the majority of gun debris is generated by the shaped charge cases. In fact, roughly 80% of all gun debris is attributed to the charge cases. The remaining debris is attributed to the charge case jackets and the loading tubes.

There exists, therefore, a need for a debris free perforating system that reduces or eliminates the debris generated upon detonation of the shaped charges.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross-sectional view of a typical shaped charge, loading tube, and perforating gun.

Figure 2 is a perspective view of a typical shaped charge and loading tube.

Figure 3 is a perspective view of a loading tube being inserted into a perforating gun.

Figure 4 illustrates an embodiment of the debris free perforating system in which the shaped charge does not have a case.

Figure 5 illustrates a cross-sectional view of an embodiment of the debris free perforating system having a solid loading tube.

Figure 6 illustrates an embodiment of the debris free perforating system in which the jacket and/or case is made from a plastic or energetic material.

Figures 7a and 7b illustrate an embodiment of the debris free perforating system in which the loading tube is a combustible cardboard tube.

Figure 8 is a sketch of an embodiment of the debris free perforating system in which the loading tube is a reinforced plastic tube or rod.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Figure 1 provides an illustration of a typical shaped charge, indicated generally as **1**, used for perforating a well casing. Typical shaped charges for use in perforating guns are discussed in U.S. Pat. No. 4,724,767 to Aseltine issued Feb. 16, 1988; U.S. Pat. No. 5,413,048 to Werner et al. issued May 9, 1995; U.S. Pat. No. 4,669,384 to Chawla et al. issued Jun. 2, 1987; and again in U.S. Pat. No. 5,597,974 to Voreck, Jr. et al. issued Jan. 28, 1997. Each of the above mentioned disclosures are incorporated by reference into this specification.

The shaped charge **1** includes a case **10**, a main body of explosive material **12**, which in the past has been, for example, RDX, 1,3,5,7-tetranitro octahydro-1,3,5,7-tetrazocine (HMX), 2,6-bis (Picrylamino)-3,5-dinitropyridine (PYX), or 2,2',4,4',6-hexanitrostilbene (HNS) packed against the inner wall of the case **10**, a primer **13** disposed adjacent the main body of explosive **12** that is adapted to detonate the main body of explosive **12** when the primer **13** is detonated, and a liner **14** lining the primer **13** and the main body of explosive material **12**. The liner **14** acts to maintain the shape of the explosive to assure proper propagation of the detonation. A detonating cord **20** contacts the case **10** of the shaped charge **1** at a point nearest the apex of the liner **14** of the charge. When a detonation wave propagates within the detonating cord **20**, the detonation wave will detonate the primer **13**. When the primer **13** is detonated, the detonation of the primer **13** will further detonate the main body of explosive **12** of the charge **1**. In response to the detonation of the main body of explosive **12**, the liner **14** will form a jet that will propagate along a longitudinal axis of the shaped charge **1**. The jet will perforate a formation penetrated by the wellbore.

In a typical shaped charge **1**, the case **10** greatly contributes to the penetration performance of the shaped charge **1**. The case **10** (typically steel or similar) provides substantial inertial confinement, thereby enhancing the proportion of explosive energy transferred to the collapsing liner **14**, and hence the penetrating jet.

Several shaped charges **1** may be spatially arranged in a pattern (a spiral pattern, for example) in a device called a perforating gun. The shaped charges **1** are ballistically connected via the detonating cord **20** or some other means. In general, perforating guns are either capsule guns, which are essentially a metallic strip or similar device onto which the shaped charges **1** are attached, or hollow carrier guns as shown in Figures 1-3.

For a typical hollow carrier gun, one or more shaped charges **1** are housed within a loading tube **22** for transport. The loading tube **22** can house the shaped charges **1** at desired orientations, or in a linear fashion. A jacket **24** is used to both secure the shaped charges **1** to the loading tube **22** and to maintain the orientation of the shaped charges **1**. Once the loading tube **22** is ready for delivery downhole, a perforating gun **30** is used to carry the loading tube **22** and housed shaped charges **1**.

Conventionally, as shown in Figs. 2 and 3, the shaped charges **1** and jackets **24** are inserted into the loading tube **22** until the jackets **24** shoulder against the loading tube shoulders **23**. Once all of the shaped charges **1** are secured, the loading tube **22** is inserted into the interior of the perforating gun **30**. The gun **30** then transports the shaped charges **1** downhole to the desired depth of perforation.

Figure 4 illustrates one embodiment of the debris free perforating system in which the shaped charge 1 does not have a case. Because, as discussed above, a typical shaped charge relies in part on its metal case to aid in perforating the well casing, it is desirable to use an explosive **12** that compensates for the elimination of the case. In one embodiment of the present invention, the caseless shaped charge **1** shown in Fig. 4 contains a larger amount of explosive **12**. For example, the caseless shaped charge **1** may contain 2 to 3 times the explosive **12** as similarly sized metallic cased charges to obtain equivalent penetration performance.

In another embodiment of the caseless shaped charge **1** shown in Figure 4, the explosive **12** comprises a densified explosive **12** that possesses the beneficial confinement properties usually afforded by the case. The densified explosive **12** is formulated to not expand as quickly, therefore increasing the duration of its primary pulse. The densified explosive **12** delivers more of its energy to the liner **14** during the primary pulse, and therefore relies less on subsequent sustained impulse.

In one embodiment, the explosive **12** is densified by blending it with some inert heavy materials such as powdered metals. The inserted powdered metals can include tungsten, iron,

copper, and lead, for example. The resulting blend provides more mass at the detonation front, which delays expansion due to the explosive cloud mass, and hence increases primary impulse detonation.

In a typical shaped charge, the case and liner maintain the shape and the integrity of the explosives. As discussed above, in the embodiment of the debris free perforating system shown in Fig. 4, the shaped charge **1** does not have a case. During transport, the liner **14** acting alone is generally unable to maintain the shape of the explosive **12**. Thus, alternative methods of maintaining the integrity of the explosive **12** must be incorporated.

One method of maintaining the integrity of the explosive **12** in the caseless shaped charge **1** is to use a solid loading tube **36**, as shown in cross-section in Fig. 5. Hollow cavities **38** formed in the solid loading tube **36** provide housings and support for the shaped charges **1**. Suitable materials for the solid loading tube **36** include low density plastic materials, Styrofoam™ or paper, for example. Typically, the detonation of the shaped charge **1** will incinerate the solid loading tube **36**.

Referring back to Fig. 4, yet another method of maintaining the integrity of the explosive **12** in a caseless charge **1** is to use a suitable binder that will not melt or slump when exposed to the desired operating temperature. For lower temperature applications (generally below 250 °F), suitable binders can be thermoplastics such as Viton™, Kel-F-800, THV, Polyethylene, Nylon, or PVC, for example. Other suitable binders include any polymeric material having a service temperature meeting or exceeding the desired operating temperature of the application.

For high temperature applications, thermosetting plastic binders can be used as the explosive binder. Typical thermosetting plastics do not have a melting point, but do decompose when exposed to high temperatures. In one embodiment of using a thermosetting plastic binder, the explosive **12** is of the castible type where the binder is in a liquid state during production. The explosive **12** is cast in a mold of the desired shape, and the binder reacts to form a crosslinked non-melting plastic. Suitable plastic systems for castible explosives include polyesters, polyurethanes, polyamides, polyimides, and epoxies, for example. In another embodiment of using a thermosetting plastic binder, the explosive **12** is of the pressed type.

Another embodiment of a suitable binder for the explosive **12** is a thermoplastic-thermosetting polymer useful as a binder for pressed or extrudable explosive. In this embodiment, the thermoplastic-thermosetting binder comprises Elvamide™ 8061 or 8063

To enhance the consumption of the jacket **24** and/or case **10**, an oxidizer or oxidizer/powdered metal blend is added to the plastic or energetic material. Such oxidizers can be added during the forming process by direct addition to the melted polymer in the cast of a thermoplastic material. Alternatively the oxidizers can be added to the uncured resins of a thermosetting system. Suitable oxidizers can be ammonium nitrate, potassium nitrate, sodium nitrate, strontium nitrate, barium nitrate, ammonium perchlorate, potassium perchlorate, sodium perchlorate, RDX, or HMX, for example. Suitable powdered metals can be aluminum, magnesium, boron or zirconium, for example.

Another embodiment of the debris free perforating system uses jackets **24** and/or cases **10** fabricated from very thin metal that generate small fragments upon detonation of the explosive **12**. The small fragments can embed themselves in the wall of the perforating gun **30** so as to not be carried by the well fluids. In the case of the thin metal comprising copper, the metal case may expand like a balloon without fragmenting and actually paste itself to the inside of the perforating gun **30** in one piece.

Similarly, another embodiment of the debris free perforating system uses jackets **24** and/or cases **10** fabricated from thin, low-mass glass and ceramic materials. The fragments generated during detonation would be in the form of fine particulates that will not compromise the integrity of the flow of the well fluids.

Figures 7a and 7b illustrate another embodiment of the debris free perforating system in which the loading tube **22** is a combustible cardboard tube. Figure 7a illustrates a spiral wrap cardboard tube and Fig. 7b illustrates a convoluted cardboard tube. To ensure incineration in an oxygen deficient environment, the loading tube **22** may be coated with an oxidizer filled paint **40**. One embodiment of a suitable coating is a polyester or polystyrene thermosetting resin filled with an oxidizer such as ammonium nitrate, potassium nitrate, sodium nitrate, strontium nitrate, barium nitrate, ammonium perchlorate, potassium perchlorate, RDX, or HMX, for example. Additional energy can be supplied by incorporating powder metals such as aluminum, magnesium, boron, or zirconium.

Another embodiment of the debris free perforating system is illustrated in Fig. 8. In this embodiment, the loading tube **22** is a thin-walled plastic tube or rod made of one of the previously mentioned engineering plastics formulated with reinforcing fibers **42** (such as glass, carbon, or Kevlar™) and a suitable oxidizer such as ammonium nitrate, potassium nitrate, sodium

nitrate, strontium nitrate, barium nitrate, ammonium perchlorate, potassium perchlorate, sodium perchlorate, RDX, or HMX. Additional energy can be supplied by incorporating powder metals such as aluminum, magnesium, boron, or zirconium.

Example

The following example details the results of debris tests run on two embodiments of the present invention. The "caseless" shaped charges used in the tests were very thin (0.060" thick) 8 gram plastic combustible cases. The results are compared to test results for a conventional steel-cased charge of equal size.

Test I. In the first test, five (5) of the above-described "caseless" shaped charges were carried in a 1-foot gun. The charges were loaded into a Styrofoam™ loading tube without the use of a jacket. The charges were detonated and the debris was collected. The amount of debris collected was approximately 2.1 grams of debris per charge. Most of the debris was actually liner powder that did not jet and therefore remained in the gun. It was estimated that the non-liner debris remaining in the gun was less than 1 gram per charge. For reference, the conventional steel-shaped cased charge yielded approximately 240 grams per charge.

Test II. In the second test, four (4) of the above-described "caseless" shaped charges were carried in a 1-foot gun. The charges were loaded into a cardboard loading tube without the use of a jacket. The charges were detonated and the debris was collected. The amount of debris collected was approximately 6.3 grams of debris per charge. The debris was a combination of liner powder and small (approx. ¼") cardboard pieces. Again, for reference, the conventional steel-shaped cased charge yielded approximately 240 grams per charge.

The above discussed data is provided in tabular form in Table I below.

TABLE I

Conventional Shaped Charge v. "Caseless" Shaped Charge

	<u>Conventional Steel-Cased Charges</u>	"Caseless" Charges in Styrofoam Loading Tube	"Caseless" Charges in Cardboard Loading Tube
Grams of Debris Per Charge	240	2.1	6.3

blended with a stoichiometric amount of an epoxy resin, such as Epon™ 828. The blend is then cured with a latent curing agent such as Dicyandiamide (DICY), for example. The cured blend can then be coated on to the explosive **12** using the water slurry method. Usually a 2 to 10 percent by weight coating is applied. When pressed at 212-250 °F, the binder cures to form a non-melting thermoset polymer stable to 400 °F. Alternatively, the explosive formulation can be pressed at room temperature and cured in an oven at elevated temperature.

Another embodiment of a thermoplastic-thermosetting binder for use in a pressed or extruded explosive is a fluoropolymer such as Dupont Viton™, 3M Fluorel 2175, or Dyneon THV, for example. These fluoropolymers can be formulated with RDX or HMX using the water slurry process. The resulting explosive molding powder is pressed to shape using standard explosive pressing technology. In their natural state, these materials are thermoplastics and will soften and slump at temperatures exceeding approximately 250 °F. However, exposure to electron radiation (so called e-beams) causes the polymer to cross-link and cure by well known mechanisms. E-beam curing increases the glass transition temperature and melting points of these polymers. Even in instances where the e-beam only cures the skin of the polymer, the skin is sufficiently toughened to prevent deformation of the caseless shaped charge **1** exposed to elevated temperatures.

Figure 6 illustrates another embodiment of the debris free perforating system in which the jacket **24** and/or case **10** is made of a plastic or energetic material to support the explosive **12** and attach the shaped charge **1** to the loading tube **22**. The plastic or energetic material is combustible such that upon detonation of the shaped charge **1**, the jacket **24** and/or case **10** does not leave any debris. Suitable plastics include Nylon, PEEK, Polyimide, Polysulfone, PVC, CPVC, Polyethylene, Torlon™, PVDF, Teflon™, CTFE, CTFE/E, Polyethylene, Phenolic, Polypropylene, or any other plastic or filled plastic possessing adequate thermal stability for use at the desired operating temperatures. In one embodiment, the jacket **24** is made of paper.

In this embodiment of the debris free perforating system, the shape of the explosive **12** is maintained by the case **10** and may be fabricated with a meltable binder such as wax, for example. The jacket **24** and/or case **10** is made as thin as possible to enhance its combustion by the explosive **12** contained in the shaped charge **1**. Typical jacket **24** and/or case **10** thickness in this embodiment is between 0.010 and 0.060 inches.

The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such are intended to be included within the scope of the following non-limiting claims.

CLAIMS

1. A debris free perforating system, comprising:
   a caseless shaped charge having explosive material.

2. The debris free perforating system of claim 1, wherein the caseless shaped charge is housed within a solid loading tube.

3. The debris free perforating system of claim 2, wherein the solid loading tube is made from low density plastic.

4. The debris free perforating system of claim 2, wherein the solid loading tube is made from Styrofoam™.

5. The debris free perforating system of claim 2, wherein the solid loading tube is made from paper.

6. The debris free perforating system of claim 1, wherein the explosive material further comprises inert heavy materials.

7. The debris free perforating system of claim 6, wherein the inert heavy material is powdered metal.

8. The debris free perforating system of claim 7, wherein the powdered metal is tungsten.

9. The debris free perforating system of claim 7, wherein the powdered metal is selected from iron, copper, and lead.

10. The debris free perforating system of claim 1, wherein the explosive material further comprises a thermoplastic binder.

11. The debris free perforating system of claim 10, wherein the thermoplastic binder is selected from Viton™, Kel-F-800, THV, Polyethylene, Nylon, and PVC.

12. The debris free perforating system of claim 1, wherein the explosive material further comprises a thermosetting plastic binder.

13. The debris free perforating system of claim 12, wherein the thermosetting plastic binder is selected from polyesters, polyurethanes, polyamides, polyimides, and epoxies.

14. The debris free perforating system of claim 1, wherein the explosive material further comprises a thermoplastic-thermosetting polymer.

15. The debris free perforating system of claim 14, wherein the thermoplastic-thermosetting polymer is cured from a blend of Elvamide™ 8061 and an epoxy resin.

16. The debris free perforating system of claim 14, wherein the thermoplastic-thermosetting polymer is cured from a blend of Elvamide™ 8063 and an epoxy resin.

17. The debris free perforating system of claim 15 or 16, wherein the epoxy resin is Epon™ 828.

18. The debris free perforating system of claim 14, wherein the thermoplastic-thermosetting polymer is a fluoropolymer.

19. The debris free perforating system of claim 18, wherein the fluoropolymer is selected from Dupont Viton™, 3M Fluorel 2175, and Dyneon THV.

20. A method of forming a thermoplastic-thermosetting polymeric binder for pressed or extrudable explosives, comprising:

blending Elvamide™ 8061 with a stoichiometric amount of epoxy resin;
curing the blend with a latent curing agent; and
coating explosive particles with the uncured blend.

21. The method of claim 20, wherein Elvamide™ 8063 is blended with the epoxy resin.

22. The method of claim 20, wherein the epoxy resin is Epon™ 828.

23. The method of claim 20, wherein the latent curing agent is Dicyandiamide.

24. The method of claim of claim 20, wherein the blend is cured in an oven.

25. The method of claim 20, wherein the explosive is coated with the cured blend in an amount of 2 to 10 percent by weight.

26. A method of forming a fluoropolymer binder for pressed or extrudable explosives, comprising:

formulating a plastic bonded explosive using the water slurry process;
pressing the resulting explosive molding powder to shape; and
exposing the molded shape to electron radiation.

27. A debris free perforating system, comprising:

a shaped charge having a jacket made from a combustible material; and
a case made from a combustible material.

28. The debris free perforating system of claim 27, wherein the combustible material is plastic.

29. The debris free perforating system of claim 28, wherein the plastic is selected from Nylon, PEEK, Polyimide, Polysulfone, PVC, CPVC, Polyethylene, Torlon™, PVDF, Teflon™, CTFE, CTFE/E, Polyethylene, Phenolic, and Polypropylene.

30. The debris free perforating system of claim 27, wherein the combustible material is an energetic material.

31. The debris free perforating system of claim 27, wherein the jacket comprises paper.

32. The debris free perforating system of claim 27, wherein the combustible material further contains or is coated with an oxidizer.

33. The debris free perforating system of claim 32, wherein the oxidizer is selected from ammonium nitrate, potassium nitrate, sodium nitrate, strontium nitrate, barium nitrate, ammonium perchlorate, potassium perchlorate, sodium perchlorate, RDX, and HMX.

34. The debris free perforating system of claim 27, wherein the jacket and case is made from thin metal.

35. The debris free perforating system of claim 34, wherein the thin metal is copper.

36. The debris free perforating system of claim 34, wherein the thin metal is glass.

37. The debris free perforating system of claim 34, wherein the thin metal is ceramic material.

38. A debris free perforating system, comprising:

a shaped charge; and

a combustible loading tube coated with an oxidizer.

39. The debris free perforating system of claim 38, wherein the oxidizer is selected from ammonium nitrate, potassium nitrate, sodium nitrate, strontium nitrate, barium nitrate, ammonium perchlorate, potassium perchlorate, sodium perchlorate, RDX, and HMX.

40. A debris free perforating system, comprising:

a caseless shaped charge; and

a densified explosive.

41. The debris free perforating system of claim 40, wherein the densified explosive comprises an explosive blended with inert heavy materials.

42. The debris free perforating system of claim 41, wherein the inert heavy materials are powdered tungsten.

The Patent Office

INVESTOR IN PEOPLE

Application No: GB 0212621.7 **Examiner:** John Twin
Claims searched: 1 to 19 **Date of search:** 30 January 2003

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Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1	US 3237559 (Schlumberger Prospection)

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{V}:

F3A

Worldwide search of patent documents classified in the following areas of the IPC^{7}:

E21B; F42B

The following online and other databases have been used in the preparation of this search report :

online: EPODOC, JAPIO, WPI, OPTICS